

# Neutrinoless Muon-to-Positron Conversion at Mu2e

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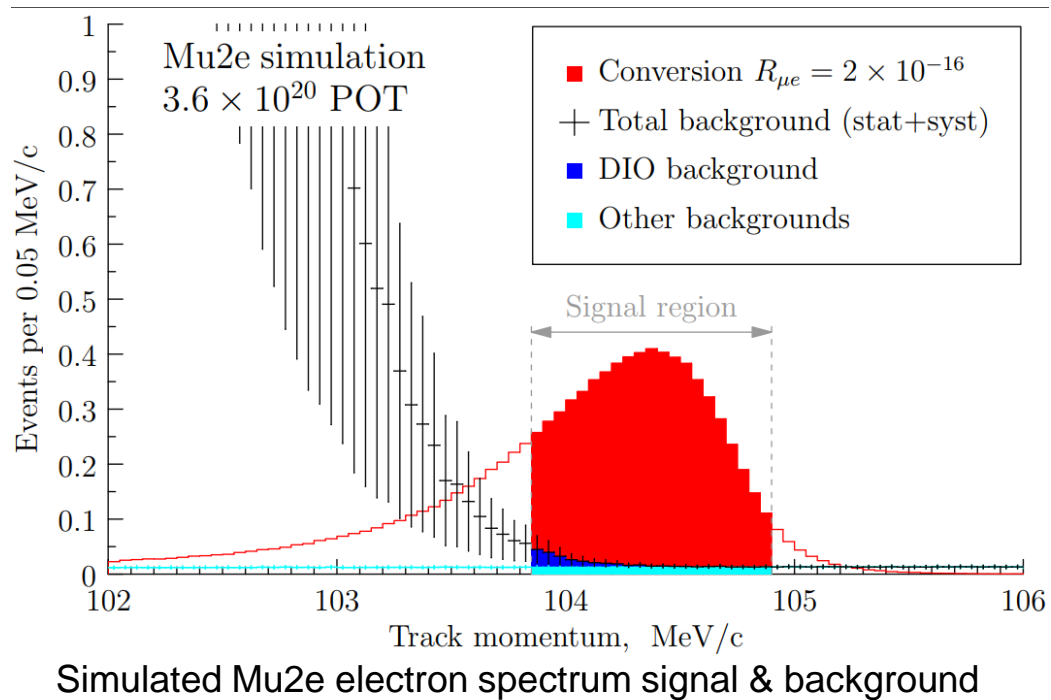
LBNL Flavor Group

Mu2e Collaboration

# Outline

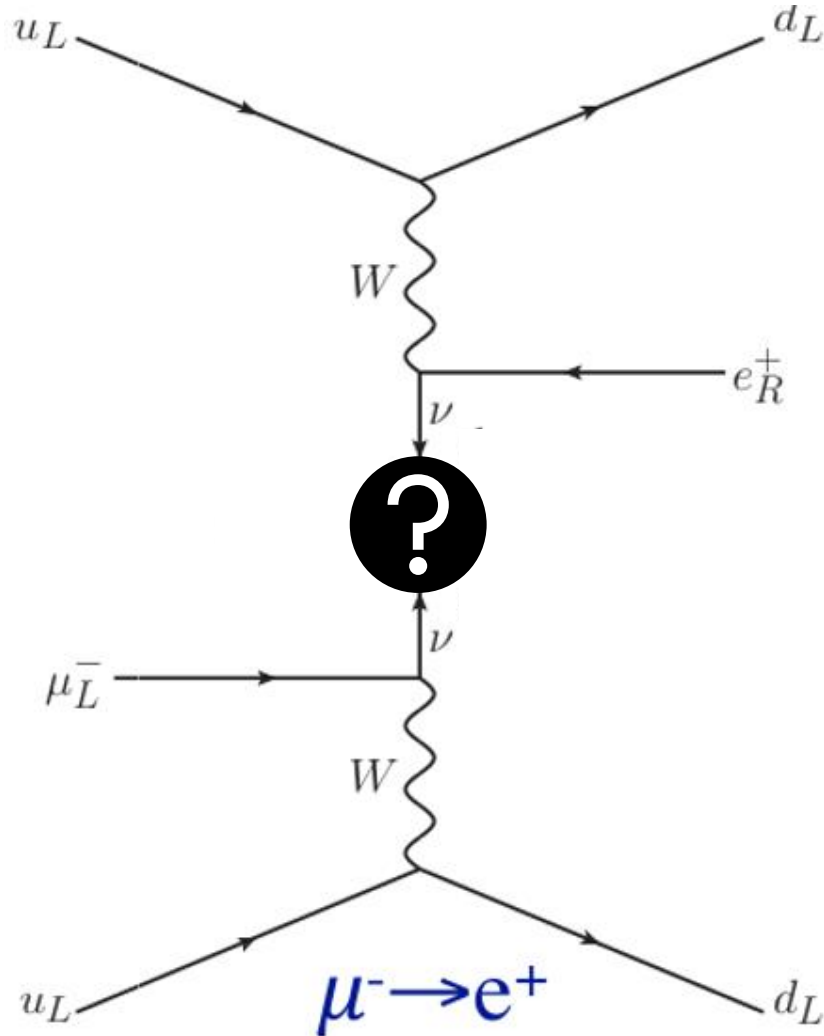
- Introduction of  $\mu^-N \rightarrow e^-N$  and  $\mu^+ + (A, Z) \rightarrow e^+ + (A, Z-2)$
- Overview of the Mu2e Experiment
- Positron Backgrounds in Mu2e
- Background Simulations

# Coherent Muon-to-Electron Conversion



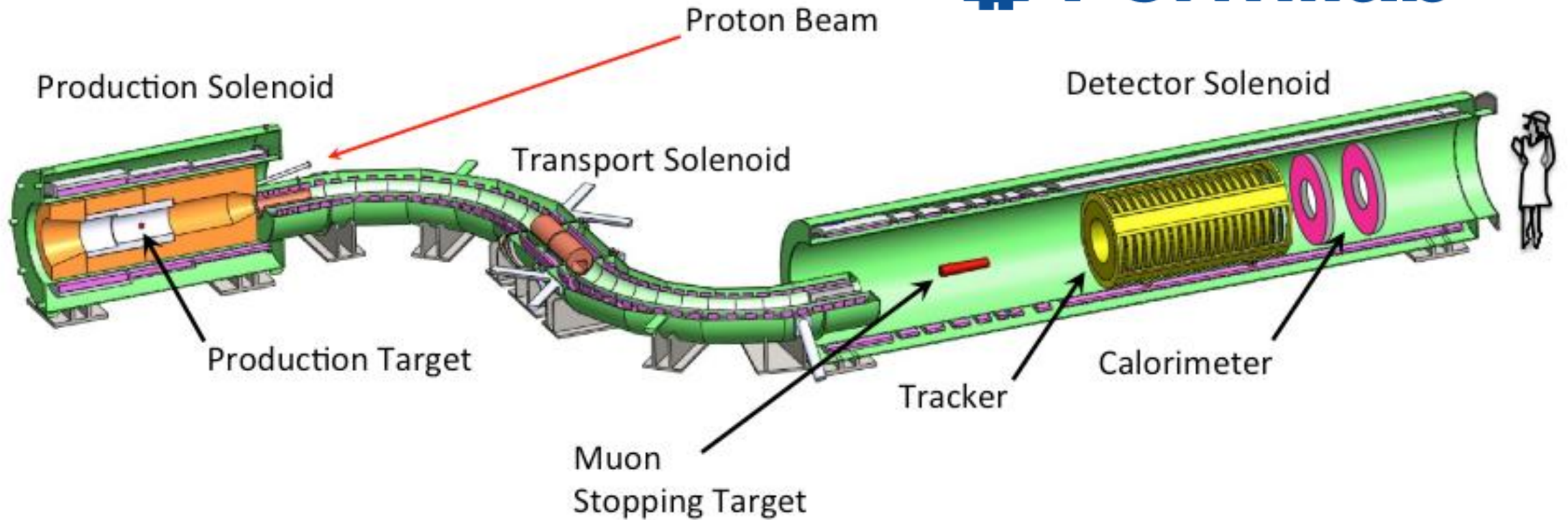
- ▶  $\mu^- + \text{Al-27} \rightarrow e^- + \text{Al-27}$
- ▶ Mu2e's primary physics goal is the observation of a monoenergetic 105.1 MeV/c electron signal
- ▶ With a single event sensitivity of  $3.3 \cdot 10^{-17}$ , any positive signal would be far higher than the SM rate  $O(10^{-55})$  and a sign of new physics
- ▶ **CLFV is featured in many BSM theories!!**
- ▶ Current experimental upper bound:
  - ▶ SINDRUM II:  $7.0 \cdot 10^{-13}$  (90% CL)<sup>[1]</sup> (Gold)
  - ▶ Normalized to ordinary muon captures

# Neutrinoless Muon-to-Positron Conversion



- ▶  $\mu^-(A,Z) \rightarrow e^+(A,Z-2)$
- ▶ A **secondary physics goal** of the experiment is detecting neutrinoless muon-to-positron conversion
  - ▶ A “free” measurement
- ▶ This process not only violates charged lepton flavor conservation but also lepton number conservation
- ▶ Process is analogous to neutrinoless double beta decay
- ▶ Signal is a **monoenergetic 92.3 MeV/c positron**
- ▶ Current experimental upper bound:
  - ▶ SINDRUM II:  $1.7 \cdot 10^{-12}$  (90% CL)<sup>[3]</sup> (Titanium)

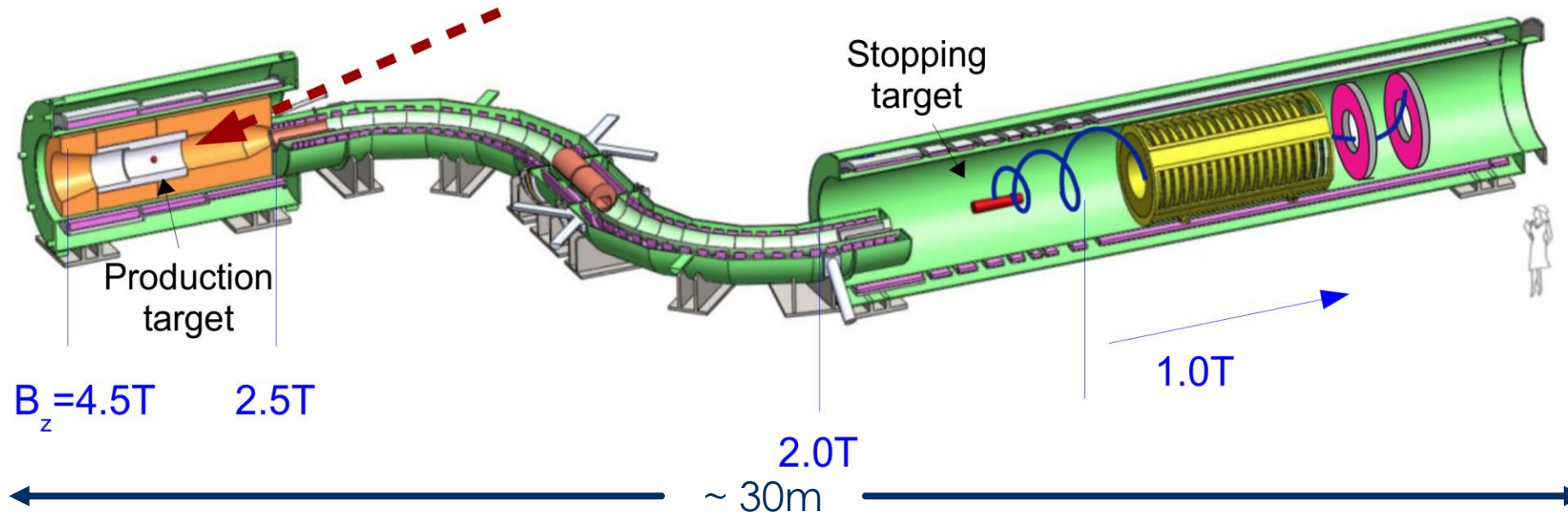
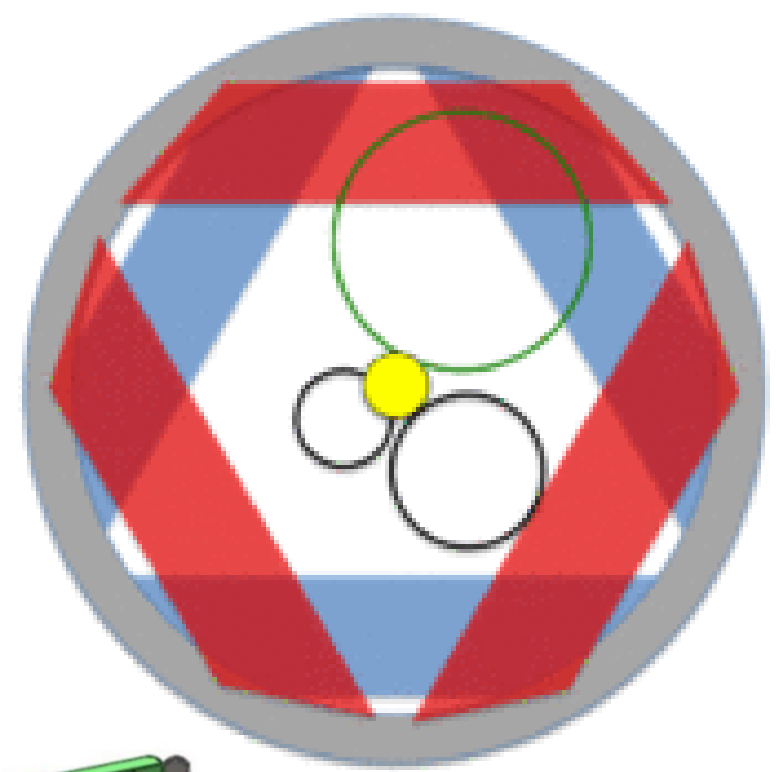
One of the feynman diagrams contributing to  $\mu^-(A,Z) \rightarrow e^+(A,Z-2)$ <sup>[2]</sup>



# Mu2e Overview

# Mu2e Straw Tracker/Spectrometer

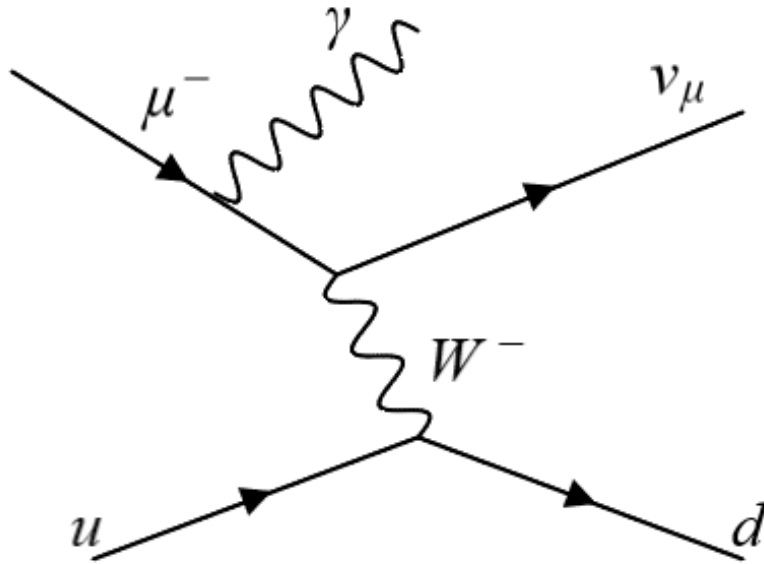
- ▶ The Mu2e tracker consists of **21,000 5mm diameter straws**
  - ▶ 18 tracker stations evenly spaced over ~2 meters
- ▶ Designed to be **low-mass** and provide **high momentum resolution**
  - ▶  $\Delta P/P \sim .1\text{--}.3\%$
  - ▶ Machine learning helps with this
- ▶ Charged particles have **helical trajectories** that we will fit in 3-D space
  - ▶ Simultaneously tracks positively and negatively charged particles



# Positron Backgrounds

- Radiative Muon Capture ( $\text{RMC}_\gamma$ )
- Radiative Pion Capture ( $\text{RPC}_\gamma$ )
- Cosmic Rays

# Radiative Muon Capture



A Feynman diagram of radiative muon capture

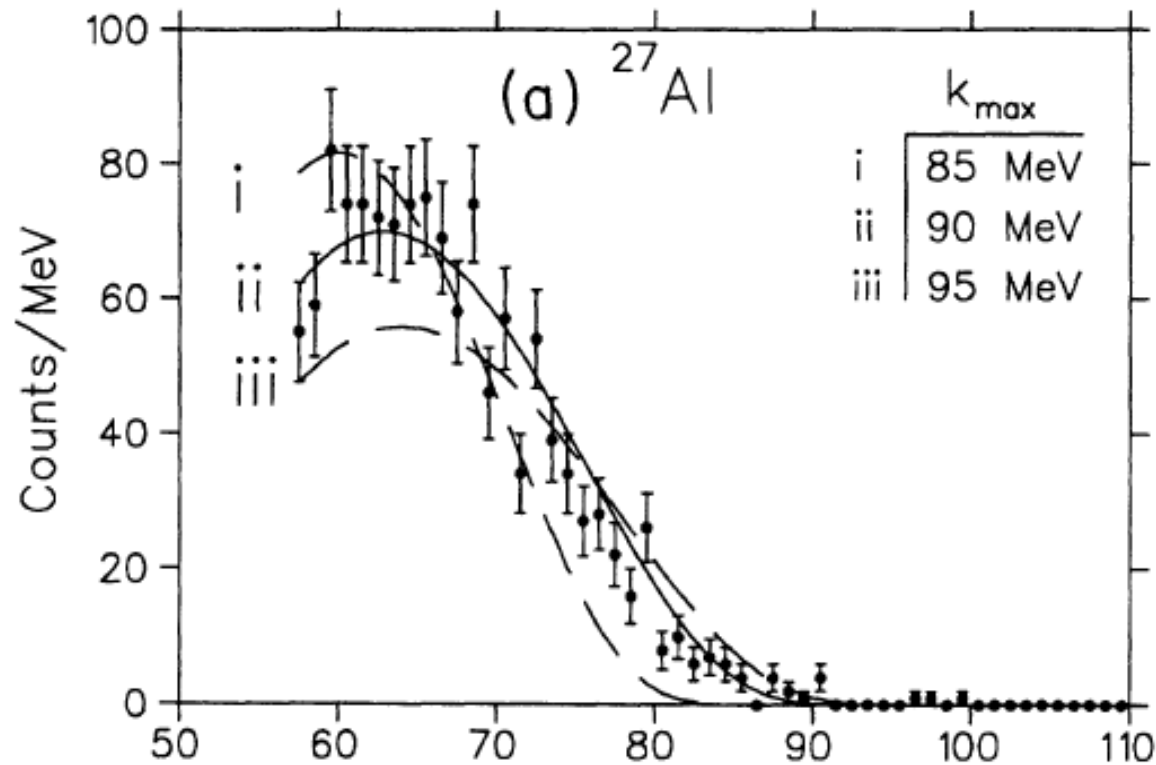
- ▶ A muon falls into an Aluminum nucleus in the stopping target and emits a photon
- ▶ This photon goes on to create an electron-positron pair
- ▶ The photon energy spectrum is modeled by the Closure Approximation

- ▶  $x = \frac{E_\gamma}{k_{max}}$

- ▶  $\frac{dN}{dx}(x) = (1 + 2x + 2x^2)x(1 - x)^2$



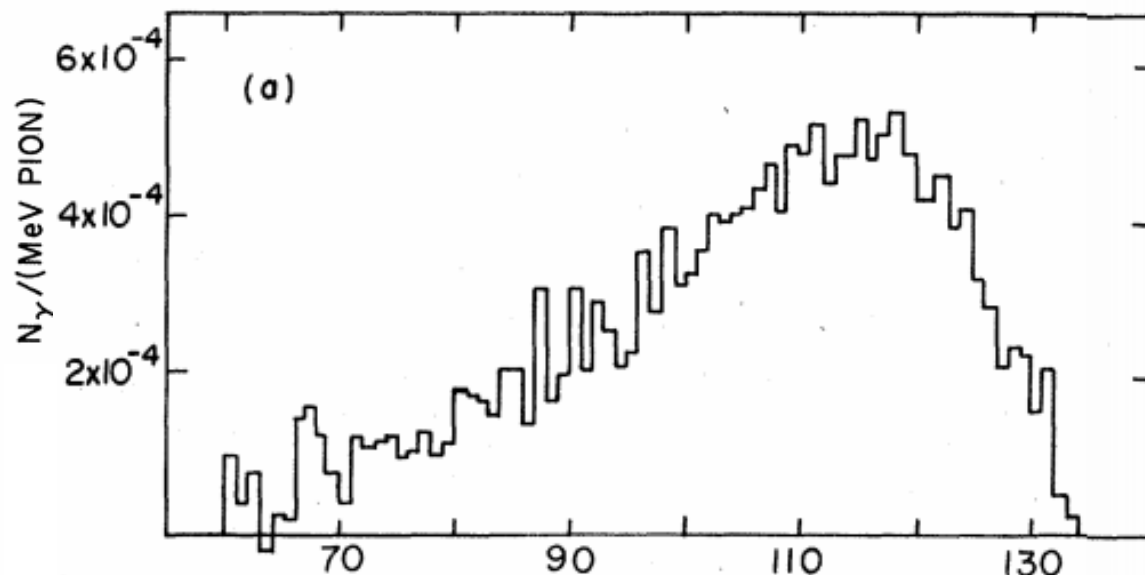
# Radiative Muon Capture



- ▶ The expected number of RMC positron **background events is heavily dependent** on the kinematic endpoint,  $k_{\text{max}}$  (How high  $\text{RMC}_\gamma$  reaches)
- ▶ TRIUMF measured RMC  $k_{\text{max}}$  at  $90.1 \pm 1.8^{[4]}$  (MeV/ $c^2$ ) but with low statistics
- ▶ **Mu2e will independently measure the RMC  $k_{\text{max}}$**

RMC gamma spectrum measured by TRIUMF with various closure approximation fits<sup>[4]</sup>

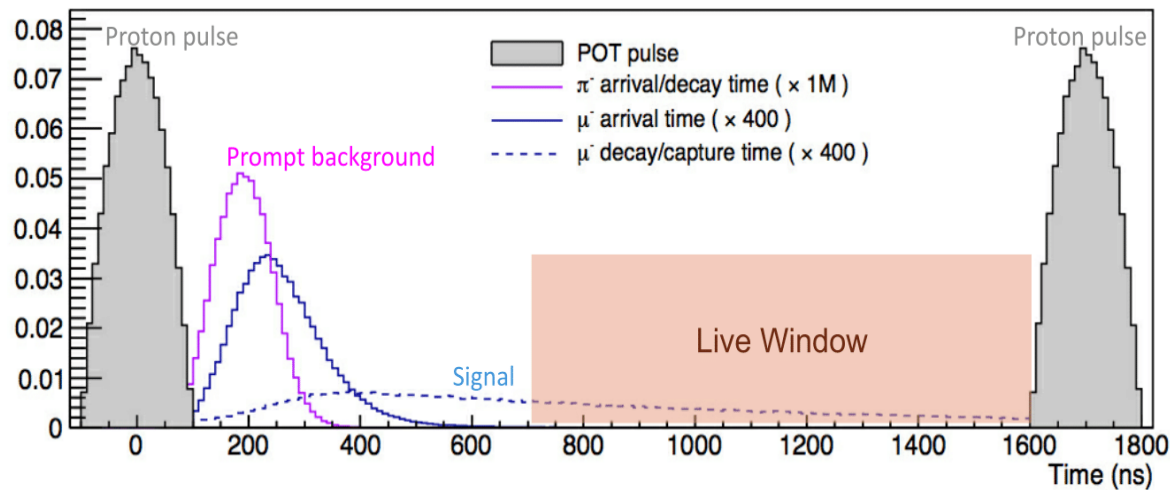
# Radiative Pion Capture



RPC Gamma Spectrum of Mg-24 as measured at LBNL [5]

- ▶ The vast majority of our pions decay into muons on their way to the stopping target
- ▶ A small number will reach the stopping target and undergo nuclear capture
- ▶ Like RMC, this process can produce a gamma ray with **high enough energy to pair produce a signal-like positron**

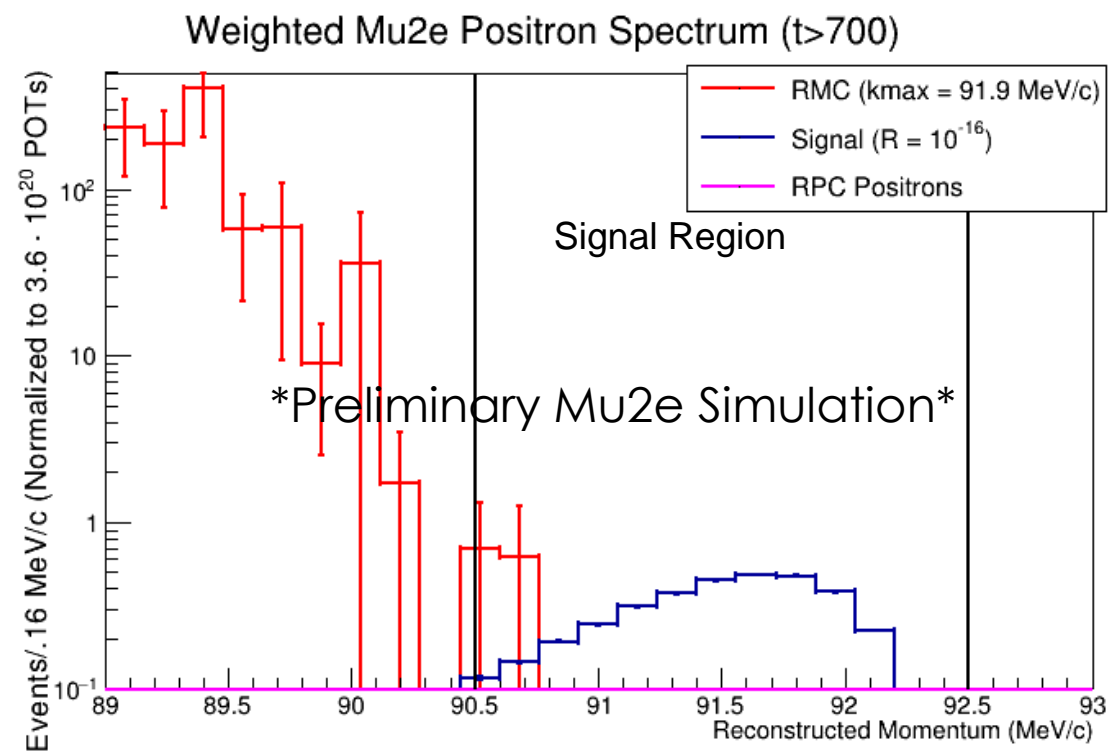
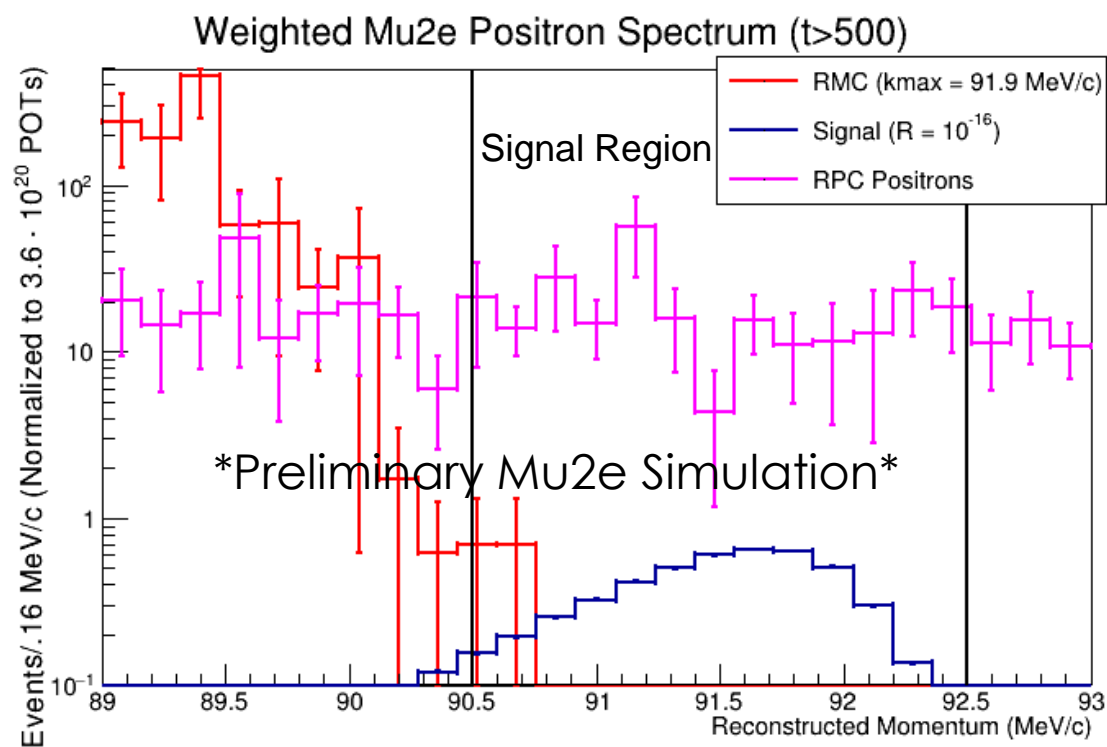
# Radiative Pion Capture



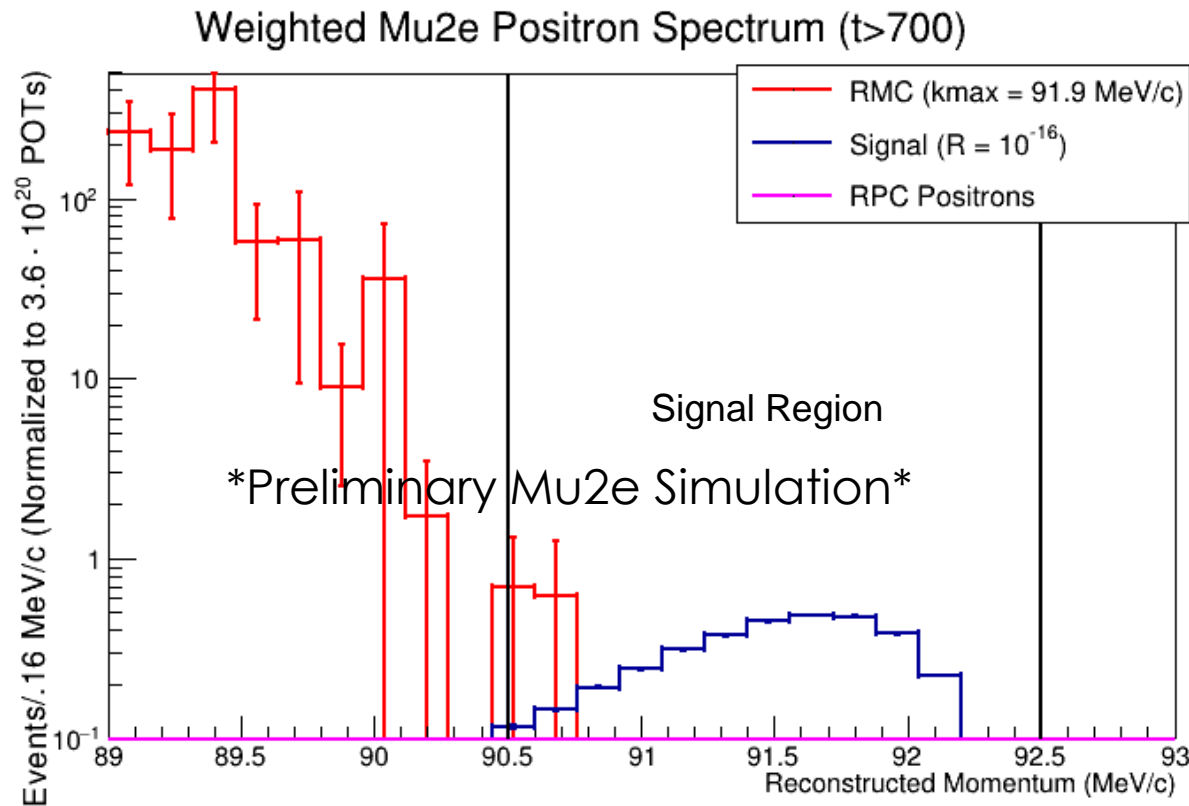
Timing profile of 1 Mu2e Cycle

- ▶ Pion stops in the stopping target are suppressed by the pion decay time
- ▶ We will further suppress RPC backgrounds by cutting on time
- ▶ Most RPC events occur shortly after proton bunch arrival at production target

# Positron Background Simulations



# Positron Background Simulations



- ▶ My work involves using GEANT4 simulations of the Mu2e environment to characterize and estimate positron backgrounds
- ▶ Analysis is at an early stage and will continue to be optimized
- ▶ Total Background Estimates: (3 years)
  - ▶ RMC : 1.2 events
  - ▶ RPC : .004 events
- ▶ Preliminary Sensitivity Estimates:
  - ▶  $\text{SES} = 2.7 \cdot 10^{-17}$
  - ▶  $\text{CL90\%} = 1.0 \cdot 10^{-16}$
  - ▶ Four orders of magnitude better than SINDRUM II
  - ▶ SINDRUM II:  $1.7 \cdot 10^{-12}$  (90% CL)<sup>[3]</sup> (Titanium)

# Acknowledgements

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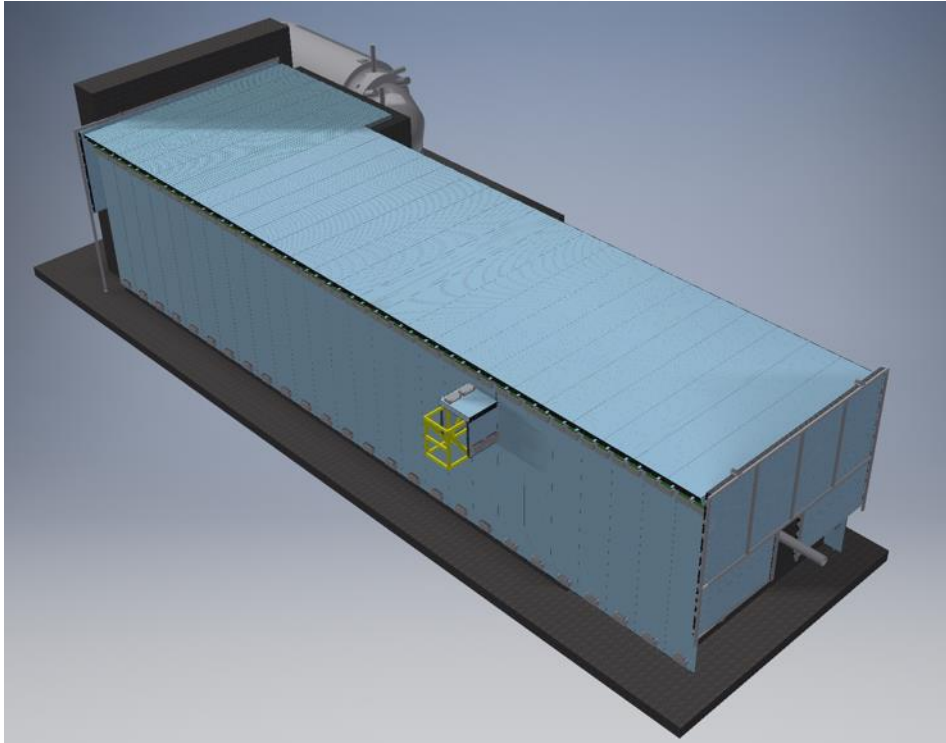
# References

- [1] W. H. Bertl et al., Eur. Phys. J. C47 337 (2006)
- [2] J. M. Berryman et al., N Phys. Rev. D 95, 115010 (2017)
- [3] J. Kaulard et al., Phys Rev. B 422, 334 (1998).
- [4] D.S. Armstrong et al., Phys Rev. C 46, 1094 (1992).
- [5] J.A. Bistirlich et al., Phys Rev. C 5, 1867 (1972).

# BACKUPS



# Cosmic Rays



In order to reach our sensitivity goals, we must detect 99.99% of all charged particles that fly into our experiment

Otherwise, 1 Mu2e signal-like event will happen once a day

Expected background contribution is on the order of .25 events over 3 years